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Sympathetic Detonation Predictive Methods

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FINAL REPORT FOR PERIOD OCTOBER 1989 - DECEMBER 1992

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13. ABSTRACT *(Maximum 200 words)*
For the past decade the U.S. Air Force has been engaged in a research program to develop an insensitive high explosive (IHE) fill for the MK-82 general purpose bomb. The reasons for this endeavor are improved safety during handling, storage, and increased sortie generation due to improved storage density and proximity to the delivery vehicles. This paper details the work that has been accomplished so far in the area of sympathetic detonation and what the main stimulus for MK-82 bombs are in a storage configuration. The MK-82 bomb is stored in a six bomb pallet. It was discovered, through experimentation and hydrocode analysis, that the pallet configuration when combined with an IHE could result in a solution for the safe storage of this bomb. In support of this program a multi-channel shock wave time of arrival recorder (MSTAR) was developed. This piece of equipment proved to be invaluable during the testing phase.

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PREFACE

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a. Messrs.Gary Parsons and Larry Pitts provided valuable advice, direction and encouragement.

b. Messrs.John Corley and George Lambert assisted in conducting testing. The High Explosives Research and Development (HERD) Facility Processing Laboratory personnel under the supervision of Mr. Arthur Spencer fabricated and loaded all explosive charges.

c. The Armament Laboratory Model Shop under the supervision of Mr. Lonnie B. English fabricated all hardware that was used for this program.

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SECTION I

INTRODUCTION

Suppression of sympathetic detonation between stored munitions has become an increasingly important issue in the 1990s for all branches of the Department of Defense. Major accidents have claimed the lives of many, cost millions of dollars in damage, and reduced operational capability.

The goal of the Air Force's IHE program is to develop insensitive energetic material fills for ultimate use in future general purpose bombs. Partial fulfillment of this goal is verified by mandatory tests carried out with the energetic material. One of the tests is sympathetic detonation.

A great deal of effort has been expended by the Air Force to solve the sympathetic detonation problem for general purpose bombs. This report is an overview of the experimental and computational work that has been performed at WL/MNME.

SECTION II

BACKGROUND INFORMATION

During the IHE development program, a series of live bomb-on-bomb (MK-82) tests was conducted using AFX-1100, trinitrotoluene (TNT), wax, and aluminum. It was discovered that no sympathetic detonation was observed for the side-by-side configuration shown in Figure 1. For all of the tests the donor bomb was nose initiated. The distance between the bombs was varied from less than 25.4 to 130 millimeters. Complete documentation and description of these tests can be found in Reference 1.

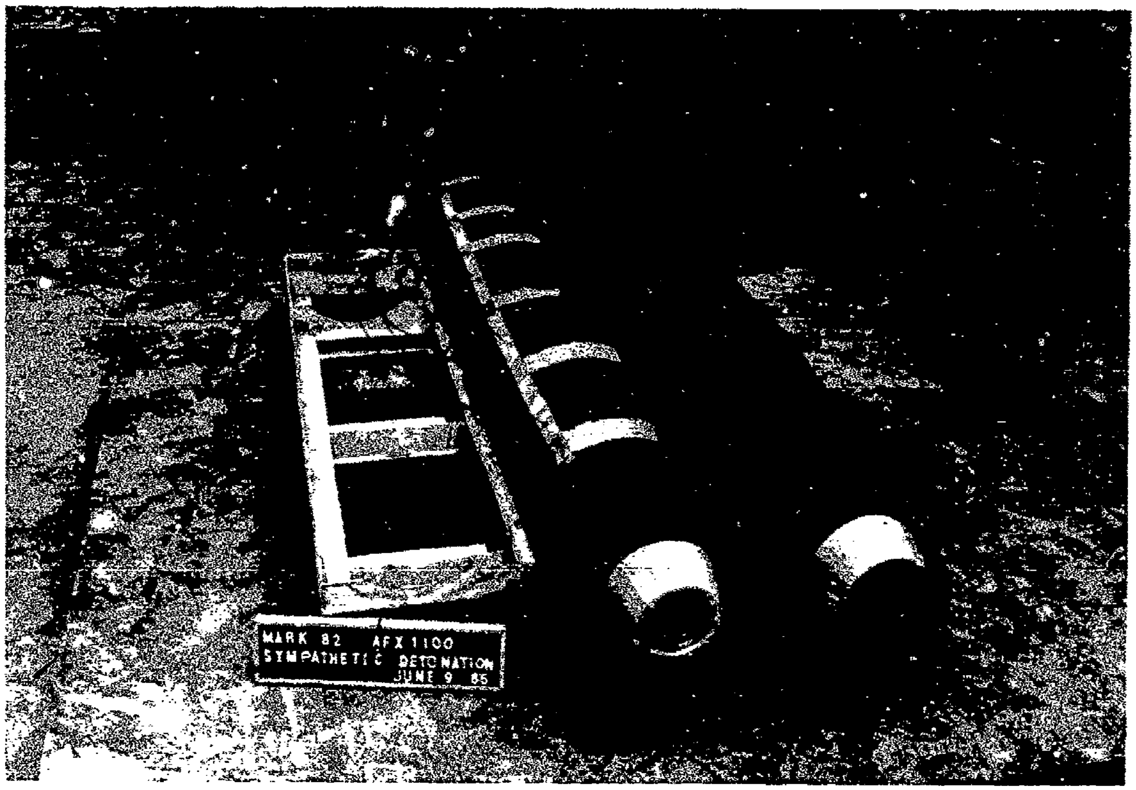


Figure 1. Bomb-on-Bomb Test

Following these tests, the bombs were placed in a steel pallet (as shown in Figure 2) which is the standard storage device for the MK-82 bomb. For symmetry and worst case conditions, the donor was placed in the bottom middle position. It was found that the left and right bottom and top center bombs did not detonate when exposed to the donor.

It was also observed that the left and right diagonal bombs consistently detonated. Since the bombs did not detonate in a side-by-side test at the same diagonal distance, it was hypothesized that the confinement of the donor bomb was due to the top center and bottom left and right bombs causing an enhancement of the bomb case velocity up to the critical initiation pressure of AFX-1100 for bombs located in the diagonal position.

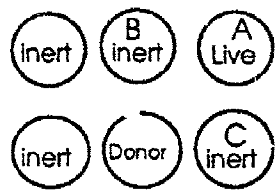
Figure 2. Six MK-82 Bombs in a Steel Pallet

A second series of tests was conducted to verify the hypothesis (Reference 2). The tests were designed to alleviate some of the confinement of the donor by elevating the top row of bombs. The layout is shown in Figure 3. For the bomb diagram in Table 1, all distances are position of closest approach from bomb to bomb.

The minimum separation distance horizontally and vertically for the bomb case was 13 mm (bomb c). Table 1 below shows the five tests that were performed and their results.

TABLE 1. SYMPATHETIC DETONATION TEST RESULTS

AFX-1100 (500-POUND BOMB)



Distance From Donor Bomb (mm)

Test	B	A	C	A	B & C
1	133	230	13	NO DETONATION	NO DETONATION
2	83	200	13	NO DETONATION	NO DETONATION
3	13	133	13	DETONATION	NO DETONATION
4	76	180	13	NO DETONATION	NO DETONATION
5	41	160	13	DETONATION	NO DETONATION

Based on the results, it appeared the hypothesis was correct in that when the confinement was reduced (diagonal distance greater than or equal to 180 mm), the diagonal bomb did not detonate.

Table 2 is a compilation of all MK-82 sympathetic detonation tests that have been performed by the HERD facility. The tests were all conducted in the standard Air Force steel pallet and consisted of one donor bomb in the bottom middle position and one live adjacent and one diagonal bomb. The other three bombs were inert filled and used for confinement of the donor. Other than AFX-1100, which was previously introduced, there are four formulations. AFX-931 is a blast enhanced formulation consisting of hexahedron-1,3,5-trinitro-1,3,5-triazine (RDX), aluminum, and ammonium perchlorate (AP) as an oxidizer. AFX-644 is composed of TNT, 3-nitro-1,2,4-triazol-5-one (NTO), D2 wax and aluminum. PBXW 124 is a Navy formulation which contains RDX, aluminum, AP, NTO, and binder. HOO76 and AFX-770 are variations of RDX, aluminum, high bulk nitroguanidine (HBNQ), AP, and binder.

TABLE 2. SYMPATHETIC DETONATION COMPARISON OF VARIOUS EXPLOSIVE FORMULATIONS

Explosive	Side Adjacent	Diagonal
AFX-1100	NO DETONATION	DETONATION
AFX-931	NO DETONATION	DETONATION
AFX-644	NO DETONATION	NO DETONATION/DETONATION
PBXW-124	NO DETONATION	DETONATION
AFX-770	NO DETONATION	NO DETONATION

The diagonal bomb detonates more consistently, suggesting that it is subjected to higher levels of stress. Since pressures within the acceptor bomb are not being determined experimentally, a series of Hull two-dimensional hydrocode calculations was conducted to determine donor casewall impact velocities and resulting pressures within the acceptor bombs.

The first set of calculations, shown in Figure 3, was for the standard pallet condition (13 mm between donor and top adjacent bomb) where the detonation of the acceptor bomb was observed. Hugoniot and performance data were taken from Reference 3. The Hugoniot of unreacted AFX-1100 is shock velocity (Us) = 2.06 + 2.16 up at a density of 1.53 gm/cm^3 Jones, Wilkins, Lee (JWL) data are listed in Table 3.

AFX-644 MK-82 bombs loaded at a density of 92 to 95 percent of the theoretical maximum density (TMD) failed to detonate. A pilot production batch loading by Naval Surface Warfare Center Yorktown at 89 to 90 percent TMD detonated. Low density has been attributed to gas generation in some lots of D2 wax. A study to resolve the processing problems has been completed, which resulted in a modified formulation. This modification involved removing D2 wax and replacing it with more aluminum.

TABLE 3. JWL DATA FOR AFX-1100

CJ PARAMETERS

Density $\rho(gm/cm^3)$	Pressure Pcj (kbar)	Detonation Dcj (mm/usec)	Eo ($x10^{10}$)(ergs)
1.53	127	6.15	5.54

$A(10^{12})$ (ergs)	$B(10^{12})$ (ergs)	R1	R2	w
4.99	.0236	4.91	1.23	0.2

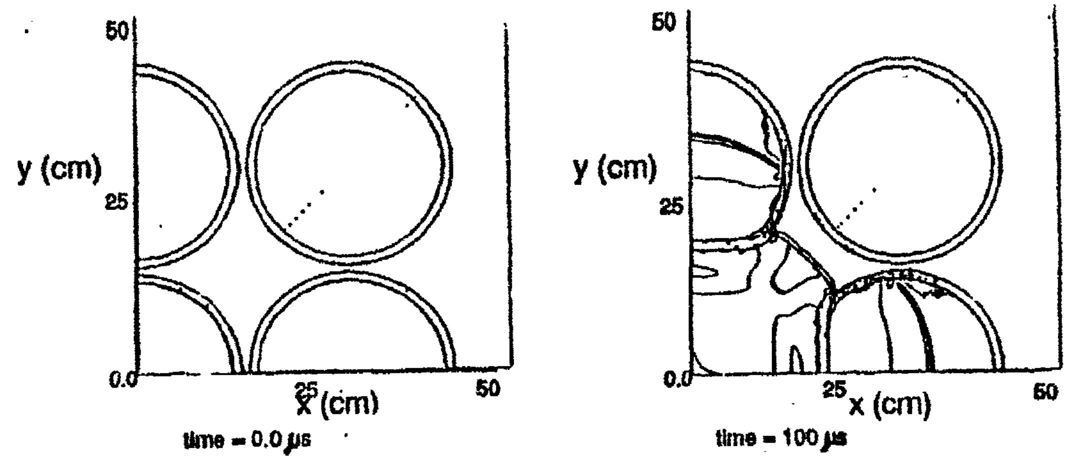


Figure 3. Hull Calculation No.1

At 100 µsecs the donor bomb has expanded and made contact with the side and top adjacent bombs. The hydrocodes are showing that the donor casewall fractures during this contact and produces a relatively thick flat plate. Time history data of donor casewall velocity and acceptor pressure are shown in Figures 4 and 5, respectively. The casewall velocity of the flat plate at impact upon the diagonal acceptor was 1.5 km/second,and the pressure induced inside the acceptor explosive was 55 kbars. By way of comparison, the critical initiation pressure for AFX-1100 as measured by the modified Expanded Large Scale Gap Test (ELSGT) is between 53 and 56 kbars. The ELSGT pulse duration is very similar to that calculated for the diagonal bomb shown in Figure 3. Thus the calculation predicts that the diagonal bomb is at the initiation threshold for AFX-1100, and the calculation agrees with the experiment.

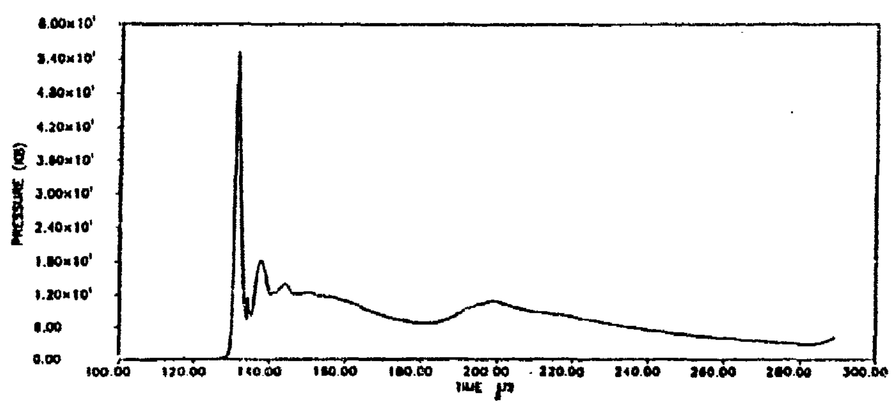


Figure 4. Hull Calculation No.1 Showing Pressure Pulse Inside of Acceptor Bomb Due to Donor Impact

The next series of calculations were performed at a non-detonating height for the diagonal bomb of 76 mm as measured vertically from bomb skin to bomb skin.

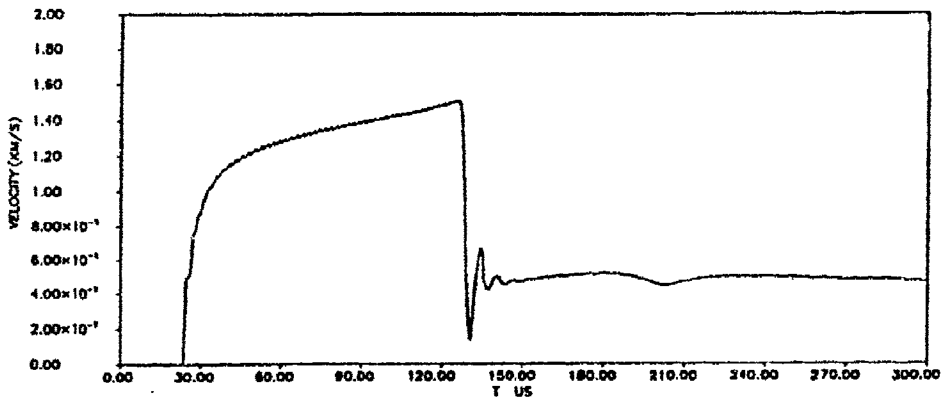


Figure 5. Hull Calculation No.1 Showing Casewall Velocity at Impact of the Donor Bomb

Notice in Figure 6 that at 100 µs the flat plate generated from the donor casewall appears to have thinned more than in the previous test (see Figure 3). Thinning of the casewall is directly related to the amount of expansion the bomb case is allowed to undergo. As a general approximation it is assumed that the bomb case will expand up to 2 times the initial radius before it breaks up. In Figure 7 the pressure induced inside the acceptor bomb is calculated to be 44.6 kbars, approximately 10 kbars below critical initiation pressure. The velocity of the thinned casewall at impact on the diagonal acceptor bomb is 1.62 km/second as shown in Figure 8. The calculation predicts no initiation in this instance and again supports the experimental observation.

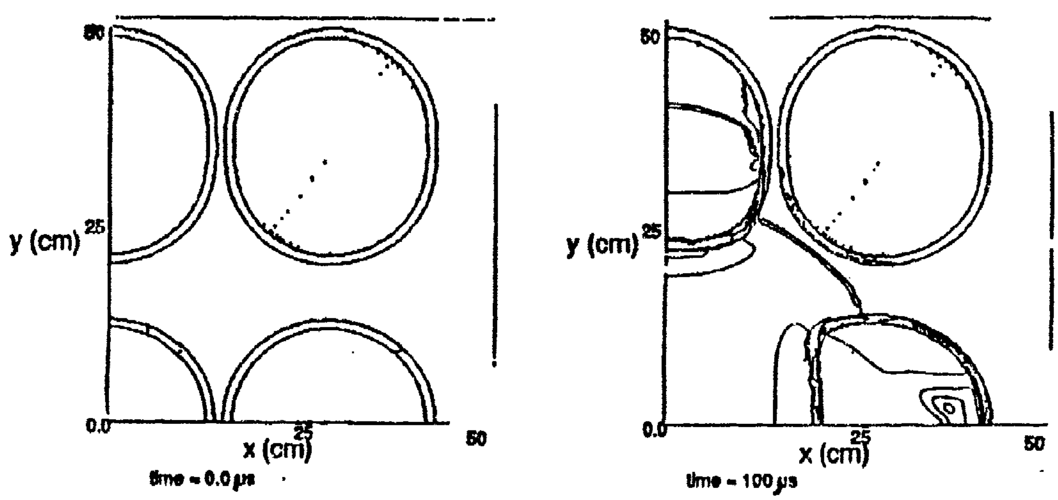


Figure 6. Hull Calculation No.2

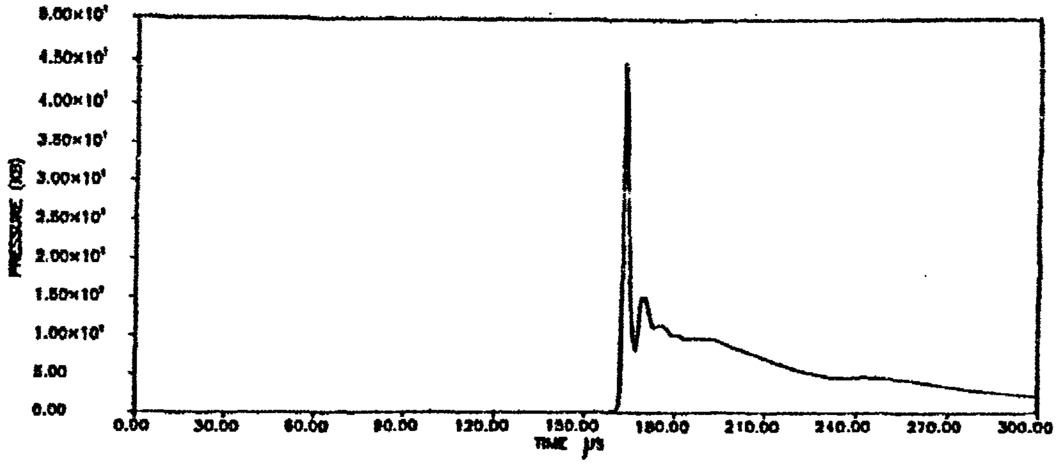


Figure 7. Hull Calculation No.2 Showing Pressure Pulse Inside of Acceptor Bomb Due to Donor Impact

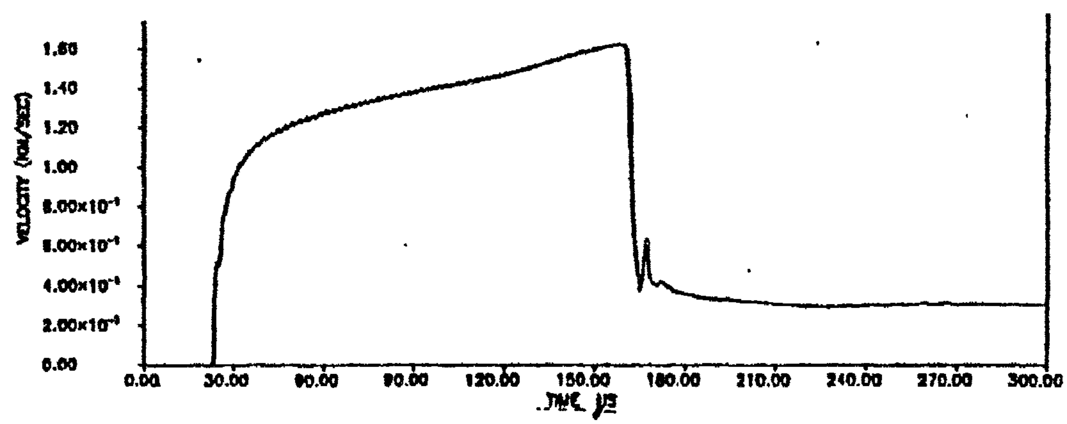


Figure 8. Hull Calculation No.2 Showing Casewall Velocity at Impact of the Donor Casewall

As the top row of bombs is raised, the donor casewall expands further, hence thins more, prior to impact with the center bomb of the top row. At impact, the donor flyer plate is formed and thinning ceases. It is recognized that the bomb, in reality, can only thin so much prior to case breakup. Based on the following calculations it is believed that the primary mechanism for the detonation of the diagonal acceptor bomb is shock to detonation transition (SDT). SDT is due to the flyer plate generated during the detonation. To verify SDT with hydrocodes, a flat plate was launched at the same velocity and thickness as the flyer plate in the standard bomb test shown in Figure 3. The flyer plate impacts a right circular cylinder with the same diameter, wall thickness, and explosive as the diagonal acceptor bomb. Figure 9 shows the setup and the pressure pulse as calculated by the hydrocodes. The pressure at the first unmixed cell inside acceptor case was 55.7 kbars.

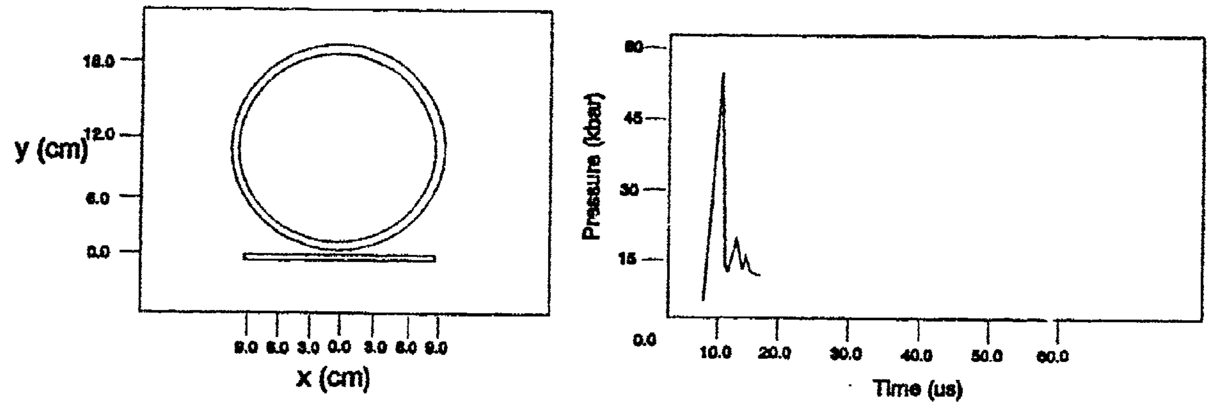


Figure 9. Hull Calculation of Flyer Plate With Pressure Pulse Signal Induced In the Acceptor

The next calculation was performed to see if the detonation products contributed to the overall energy of the flyer plate. The hypothesis was that the pallet test is a long impulse event. However, from Figure 4, very little area exists under the initial pressure pulse. This implies that the pressure duration is controlled by the thickness of the impacting casewalls with little contribution from the detonation products. Based on the calculation of the detonating donor bomb, at impact, the gases have expanded into a volume V/Vo of between 2 and 3. A calculation shown in Figure 10 was performed with 10 kbars of pressure behind the flyer plate. All the other conditions were kept the same. A complete history of the expansion isentrope of the donor bomb is shown in Figure 11. The pressure associated with this expansion is between 2 and 5 kbars.

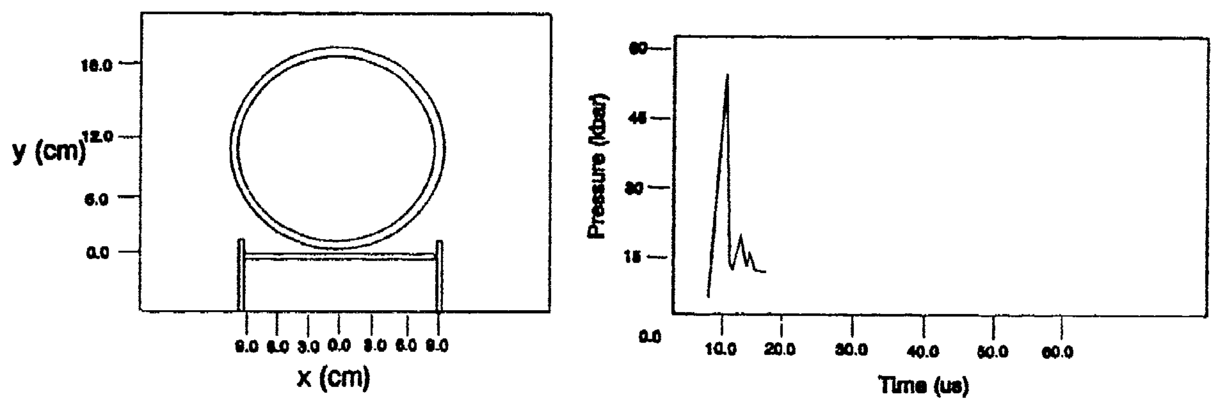


Figure 10 Hull Calculation of the Detonation Product Gas in Conjunction With the Flyer Plate and the Pressure Pulse Calculation for the Inside of the Acceptor Bomb

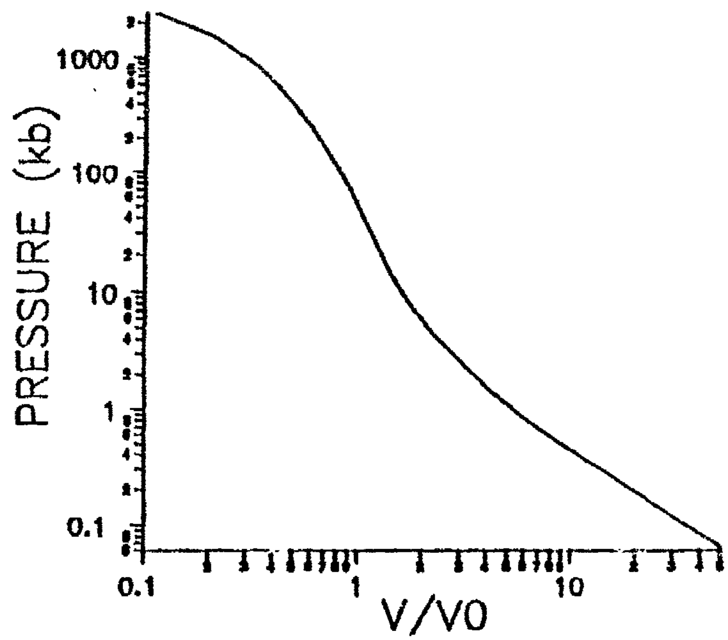


Figure 11. AFX-1100 Expansion Isentrope

To verify the results of the calculations, the detonation wave inside the acceptor had to be experimentally measured. Before the measuring could be done, an understanding of the shock wave interaction inside the pallet was necessary to identify the location of the first point of contact on the acceptor bomb from the donor casewall, since this is probably the first SDT position. This assumption was based on the Gurney velocity of the casewall and the critical initiation pressure of the explosive when exposed to a shock wave at a given amplitude and duration.

For measurement purposes it is crucial to know the first initiation site and the direction the detonation is going to propagate. Based upon these results and coupled with the ELSGT results, the initiation mechanism is postulated to be SDT due to flyer plate impact. However, mapping the shock wave time of arrival history inside the steel pallet and identifying the first initiation point is virtually an impossible task with a single-channel time of arrival recorder. At this point, effort was focused on the design and development of a multi-channel recorder capable of resolving arrival times with much less than 1 μs difference.

SECTION III

DEVELOPMENT OF MSTAR

Shock and detonation wave time of arrival (TOA) data is conveniently determined with piezoelectric pins strategically placed on the item to be tested. The current electronic data acquisition system used to transfer these TOA data to a computer, designated as the multiplex recorder, consists of a single circuit board. All of the wires leading from the piezoelectric pins tie into this system through a single data line. The TOA data are transferred to the recorder in order of TOA of the signal from the pin. This works well for gap test experiments where the direction of the propagating wave is known and a single item is being tested. For an experiment incorporating many pins in a complex array, it is impossible to establish a signal-pin relationship. It became apparent that a more sophisticated data acquisition system was required for the more complex test setup. A picture of the MSTAR is shown in Figure 12.

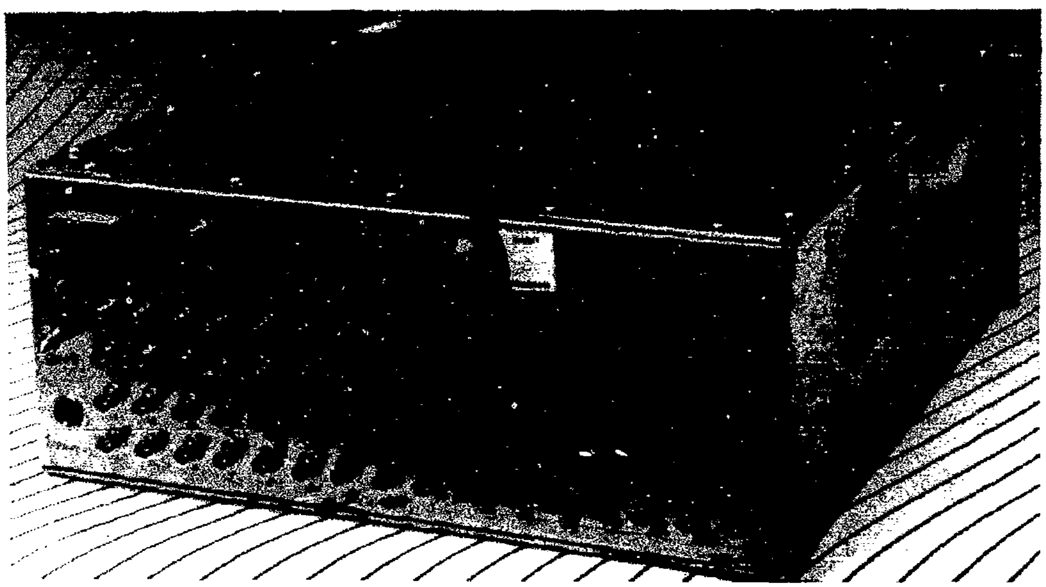


Figure 12. MSTAR

MSTAR was developed specifically for use with complex piezoelectric pin arrays, contains 64 distinct time interdependent data channels each with a resolution of 100 nanoseconds. It is a multi-channel recording device that uses digital and computer technologies to detect, record, and display the results of tests that are time varying dependent. By placing a series of piezoelectric pins in a shock wave field, the structure of the wave front propagation is obtained. A dynamic peak detector is used to detect the exact pulse peak or TOA of the pulse.

The peak detector and associated circuitry is duplicated for each of the 64 channels. Four peak detectors are organized on each of the sixteen quad channel trigger boards, Q1 through Q16, as shown in the block diagram of Figure 13. The signal from each piezoelectric pin is transferred to its respective peak detector via a connector (BNC1-BNC64) and backplane wiring. The data are then transmitted to a laptop computer via a NRS232 link where the time of arrival signals are displayed.

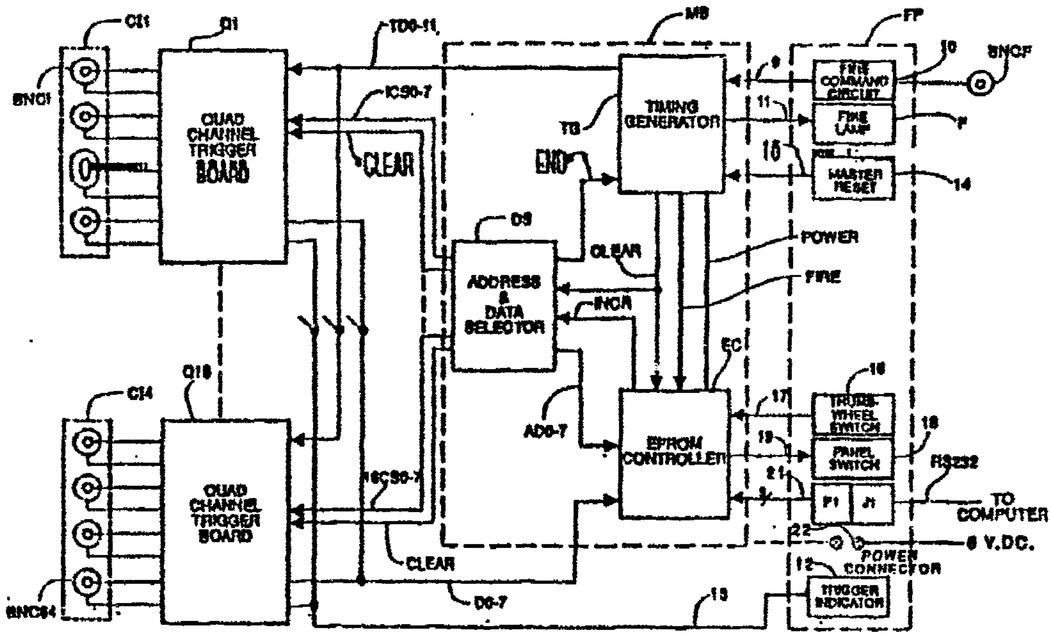


Figure 13. Block Diagram of MSTAR

A series of gap tests was conducted on three different explosives to verify the precision of the MSTAR recorder versus the multiplex recorder. The explosive used in the test shown in Figure 14 is composed of TNT and high bulk density nitroguanidine (50/50 percent by weight). The acceptor charge was unconfined, and the TOA pins were positioned on the outside surface of the explosive. In all of the tests one set of pins was connected to the MSTAR and one set to the multiplex board. The results for these tests are reported in Table 4 and show that the data from the MSTAR and the multiplex system are similar. In all tests Composition B was used as the donor material. The experimental formulation HOO76 is one that contains RDX, AP, aluminum, HBNQ, and binder.

TABLE 4. TNT/IHNQ EXPLOSIVE COMPARISON OF MULTIPLEX RECORDER WITH MSTAR

Detonation Velocity (mm/us)

Pin Position Down the Cylinder	Multi-Plex Recorder	MSTAR
1	7.5	7.4
2	7.6	7.5
3	7.5	7.5
4	7.6	7.4
5	7.4	7.7
6	7.4	7.6
7	7.5	7.5
8	7.5	7.6
9	7.6	7.5
10	7.5	7.5
	7.5 +/- 0.01	7.5 +/- 0.02

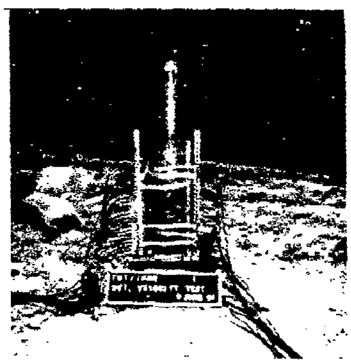


Figure 14. Go/NoGo Test for TNT/IHNQ Using a Composition B Donor With Multiplex and MSTAR System in Place

SECTION IV

SMALL-SCALE THREE-DIMENSIONAL SYMPATHETIC DETONATION TEST

As a final check of the MSTAR system in a slightly more complex geometry, an experiment was designed using steel cylinders, 203 mm outside diameter by 203 mm long with nominal wall thickness of 13 mm, filled with Composition B explosive. The cylinders were positioned side by side, with a 42-mm gap at the point of closest approach. The donor cylinder had a detonation train consisting of an RP-83 detonator, a 26-by-26 mm cylinder of Composition A-5,and a 51-by 51-mm booster cylinder of Composition B. Both the donor and acceptor cylinders were instrumented with piezoelectric pins as shown in Figure 15. The set of four pins between the cylinders was designed to provide an indication of the donor casewall arrival time along that given line. The pin array embedded in the acceptor explosive was designed to indicate the TOA of the detonation wave generated in the sympathetically detonated acceptor Composition B. A picture of the test array is shown in Figure 16. Figure 17 shows the position of the donor and acceptor with the TOA measurements listed at the proper piezoelectric pin positions. The TOA data is in microseconds. All data times are referenced back to the RP-83 detonator (t = 0 μs).

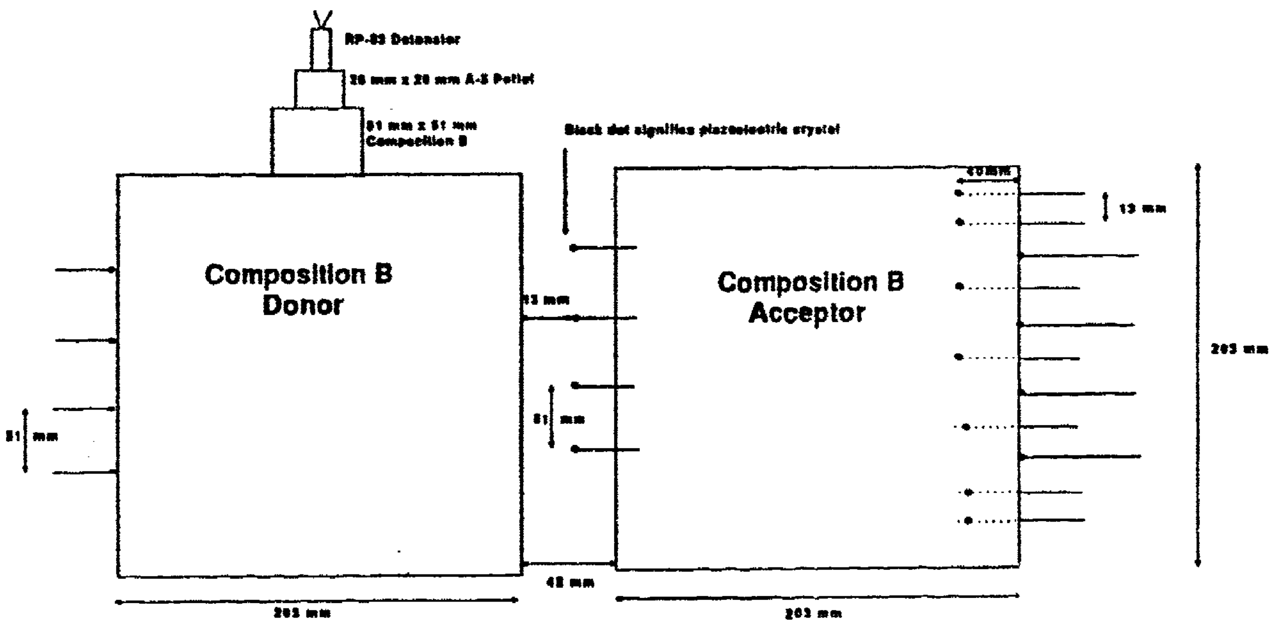


Figure 15. Schematic of the Small-Scale Test Setup

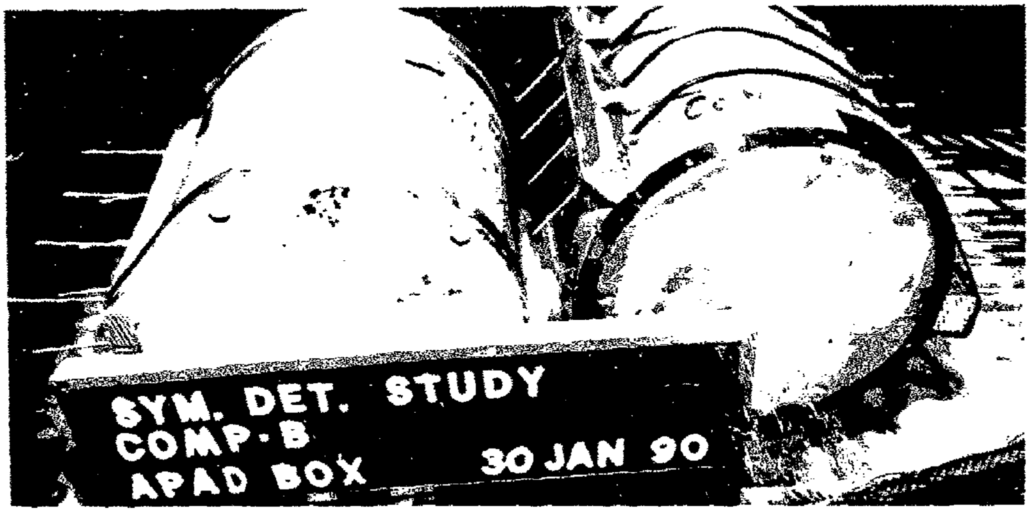


Figure 16. End View of the Small-Scale Sympathetic Detonation Setup

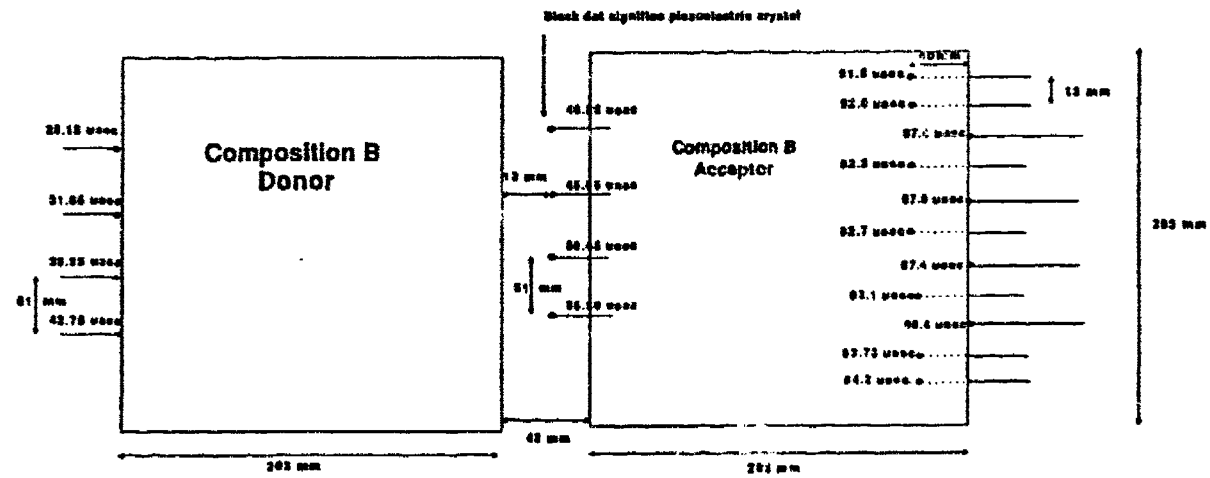


Figure 17. Drawing of the Donor and Acceptor Test Items With TOA
Data at the Specific Piezoelectric Pin Locations

The pin data was convincing in that the MSTAR could be used in complex geometry test conditions for obtaining data, and data could be used to understand how the shock and detonation wave interacted.

SECTION V

SYMPATHETIC DETONATION EXPERIMENT WITH ONE LIVE MK-82 BOMB FILLED WITH AFX-1100 AND INSTRUMENTED INERT FILLED ACCEPTOR BOMB

Based upon the results from the small-scale sympathetic detonation test, a full-scale sympathetic detonation test was conducted using one live MK-82 500 pound general purpose bomb (donor bomb) with five inert filled MK-82 acceptor bombs (see Figure 18). AFX-1100 was picked as the donor explosive for this investigation because it was well characterized and over 25 bombs were available for testing, which would allow for a reasonable database to be established.

The purpose of this experiment was to record the shock wave TOA position in an inert filled MK-82 bomb, which was placed in the diagonal position. The position of the shock wave should help identify the first point of contact between the donor and acceptor bombs. This test was repeated three times with the data being very repeatable.

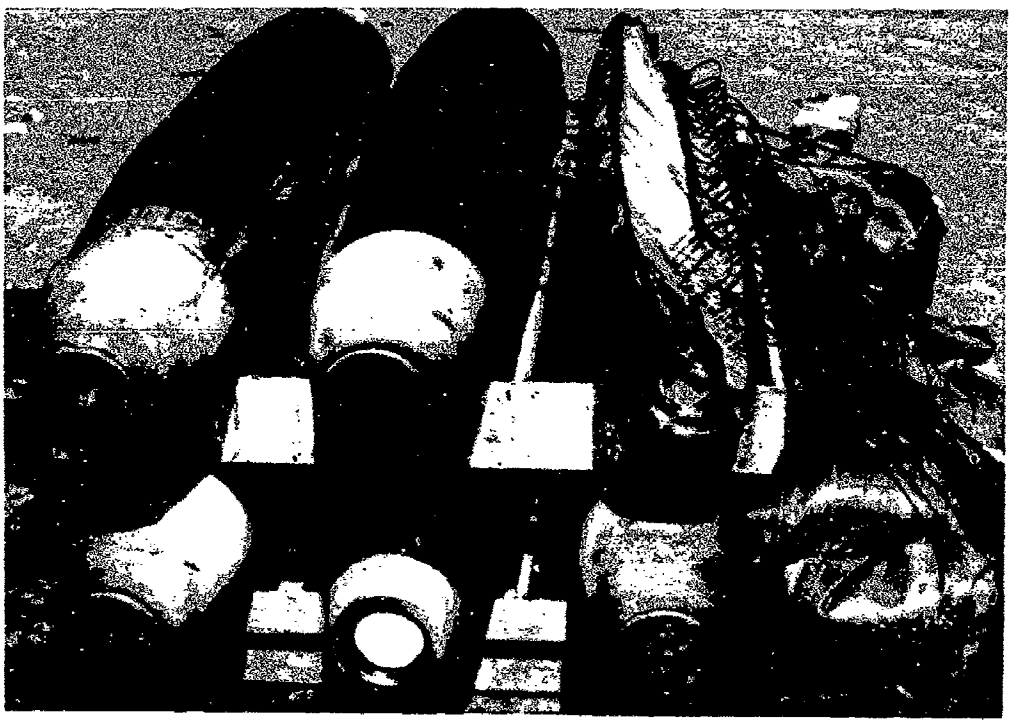


Figure 18. Overall View of the Sympathetic Detonation Test with the Instrumented Inert Acceptor Bomb in Place

The sectioned bomb was instrumented with 20 piezoelectric pins placed at specified positions in the inert filler. The inert filler (filler E) is basically a mixture of ammonium sulfate, aluminum, and Poly Wax 500. It is easily machinable and has a density corresponding to that of tritonal (1.7 gm/cm).

The sixth bomb cell was placed on a 1.8 meter by 1.8 meter by 26 mm piece of rolled homogenous armor. This was done to simulate the normal sympathetic detonation test conditions. Figure 19 shows a close-up view of the bomb section with the piezoelectric pins buried inside the inert explosive. The diagonal position for the bomb was chosen based upon results generated during the development of AFX-1100. (The data is shown in Table 1.) From these pallet tests, it was determined that sympathetic detonation occurred only in bombs located on the diagonal and not in adjacent bombs. Because the diagonal bomb appears to be the problem area,it will be the subject of this investigation. All data were recorded with the MSTAR.

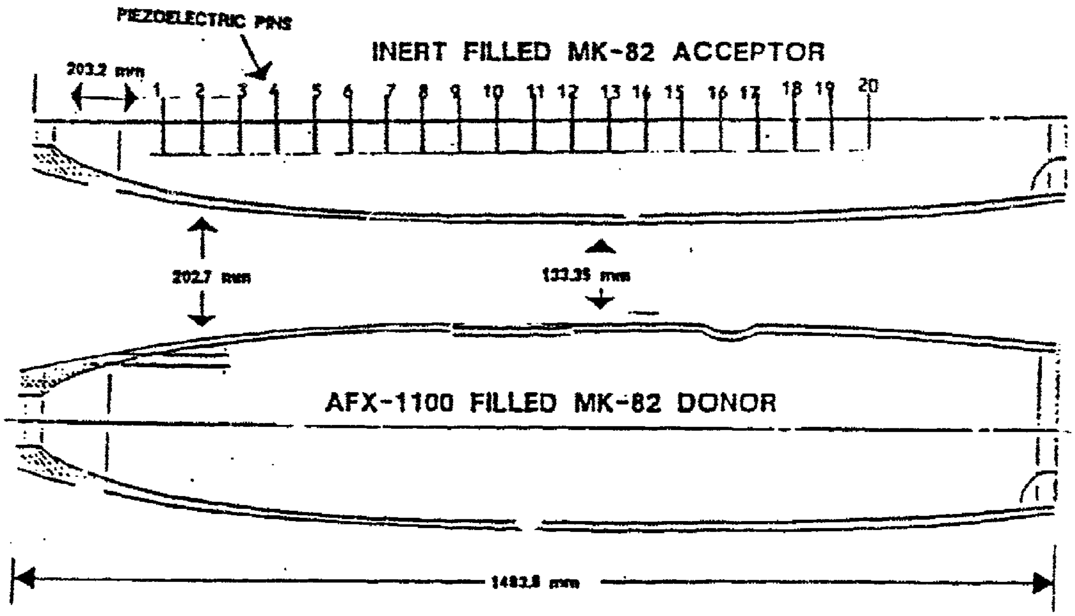


Figure 19. Close-Up View of the MK-82 Bomb Sawn Lengthwise
With Piezoelectric Pins in Place Inside the Inert
Filler E

The donor bomb consisted of approximately 180 pounds of AFX-1100 initiated with Composition C-4 packed inside the nosewell and initiated with an RP-83 detonator. (Figure 18 shows an overall view of the test setup.) All of the piezoelectric pins were buried 47 mm inside the inert medium and spaced at 51-mm increments. The distance between the donor bomb (located in the center) and the side bomb (bomb case to bomb case) is only 13 mm, whereas the distance to the diagonal bomb is 140 mm. However, because of the quality control over the tolerances of MK-82 bomb cases, there can be as much as a 5-mm variation in the casewall surface; therefore, these distances may vary slightly. Figure 20 is a schematic of the instrumented inert acceptor bomb showing the embedded piezoelectric pins.

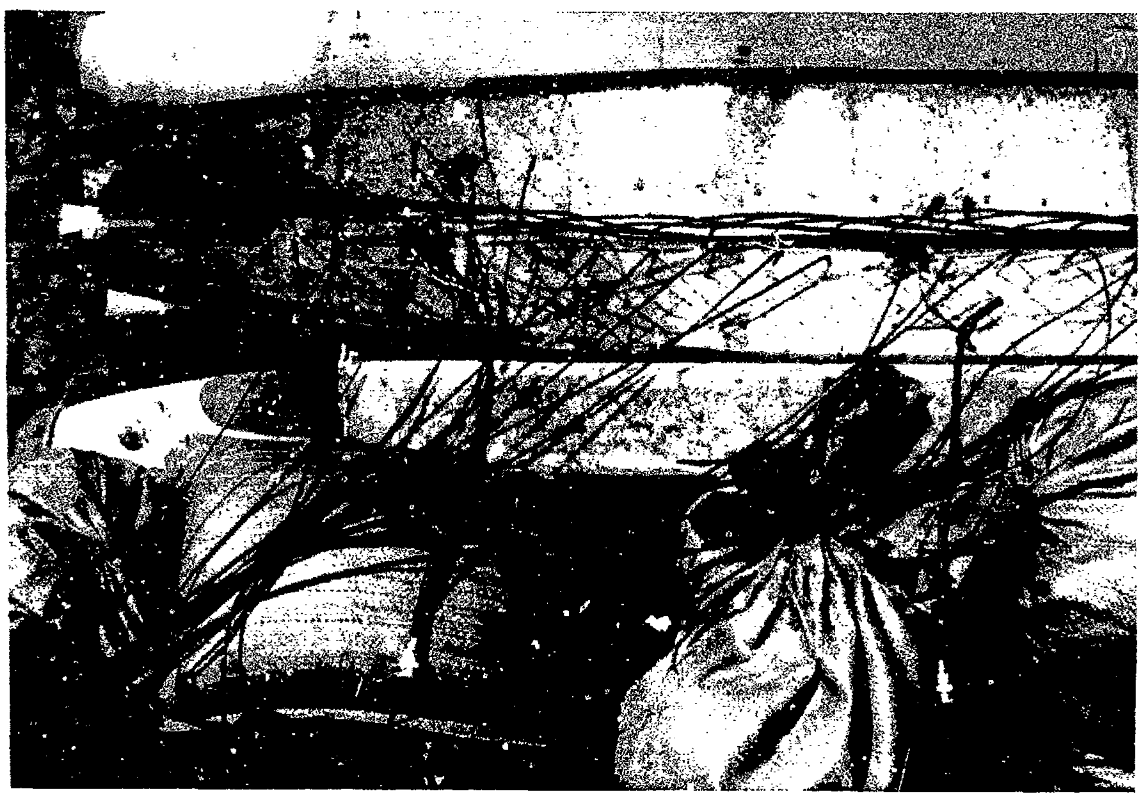


Figure 20. Schematic View of the Instrumented Inert Acceptor Bomb

Since the piezoelectric pins are triggered by low-level shock waves (0.8 kbar), it is important to know what is being measured. Available sources, which could trigger the pins, are the pressures induced by donor casewall impact or detonation products venting through the donor casewall. Previous studies (Reference 4) indicate that impact of the acceptor casewall by the donor casewall induces the initial shock wave in the acceptor explosive (see Section VI for a three-dimensional hydrocode study of impact events).

The piezoelectric pins are placed along one axis. The sensing end (quartz crystal) of the pin is positioned normal to the incoming shock wave. Figure 21 shows a close-up view of the inert instrumented bomb positioned with the piezoelectric pins aimed at the donor bomb. MSTAR has a separate memory channel for each piezoelectric pin. Therefore, each pin and cable are assigned a separate sensor number, which correlates with a specific connector on the front end of the MSTAR system.

Figure 21. Close-Up View of the Inert Instrumented Acceptor With The Piezoelectric Pins Positioned to Record the Shock wave Arrival

Each channel is connected through a specific data line from the test site to the MSTAR box. The data lines are buried under approximately 1 meter of earth until they reach the box, which is placed 76 meters from the test site. The box is shielded by a 1.2 by 1.2 by 1-meter thick concrete block. After the test, the data are retrieved by a lap-top computer at the test site.

One of the most important aspects of data gathering is protection of the required pins and cables from blast or fragmentation of the donor bomb. Note in Figure 18 that protection of the pins is provided by the inert bomb casing. However, the cables are still exposed to both compression effects or fragmentation. To reduce these hazards, cables are dressed away from the donor and over a large quantity of sandbags.

After completion of the test, a lap-top computer interrogates the memory chip, and the data is stored on a floppy disk. The experimental results are listed in Table 5. All of the TOA data are measured in microseconds, with the T = 0 (clock start time for pins) beginning with the detonator firing.

TABLE 5. SHOCK WAVE TIME OF ARRIVALS AS MEASURED INSIDE INERT FILLED ACCEPTOR BOMB

Sensor No.	Time Pin Triggered (us)
1	292.0
2	284.0
3	278.4
4	265.0
5	263.4
6	263.4
7	262.4
8	262.2
9	270.8
10	277.8
11	281.6
12	299.4
13	310.0
14	315.8
15	324.2
16	333.2
17	340.4
18	348.8

The section of bomb denoted by Sensors 7 and 8 is believed to be the first initiation site. This test demonstrates the necessity for multiple-channel recording so that signals from each pin could be identified.

SECTION VI

THREE-DIMENSIONAL PALLET CALCULATION

A three-dimensional simulation of the bomb-to-bomb interaction was performed to enable better instrumentation of the pallet test and to attempt to better define the actual quantities being measured. The objective of the pallet test was to better define the shock environment in the acceptor round. To do this, it was highly desirable to measure donor casewall impact velocity and shock transit time in the acceptor explosive. However, because of the complex geometry of the event, it was not known whether the shock waves recorded in the acceptor explosive were due to direct impact of the acceptor casewall, a shock wave traveling up the casewall, or a detonation front in the acceptor explosive. The objective of the calculation was to define the most likely detonation point and calculate the propagating wave.

The first calculation involved two MK-82 bombs in a side-by-side configuration. Because of problem-size constraints, resolution was necessarily poor with only two cells across the casewall interface. It was expected that casewall velocities would be reasonable since momentum, hence velocity and impulse, are conserved. However, no attempt was made to calculate pressure since quantity is a strong function of resolution. The acceptor bomb was modeled with an inert fill corresponding to AFX-1100.

The initial setup is shown in Figure 22. The calculation sequence is shown in Figures 23 through 26. The dots indicate the location of time-history data gathering points. The plots shown are split contour plots. The plot on the left half of the frame represents a slice in the x-z plane at y = 0.425 cm. On the right half is a slice in the x-y plane at z = 53.1 cm. The four time-history stations centered at z = 54 cm represent pin locations in the test. It was hoped that a reasonable casewall velocity could be obtained by differentiation between each pin signal.

By 200 μs (Figure 24), the donor casewall has expanded to within a centimeter of the acceptor bomb. It appears the initial impact will be between 45 and 55 cm. Note also that the skewed appearance of the donor bomb in these calculations is a result of mesh size in the y direction. This was done as a cost savings measure. While this may have some effect on the centerline x-direction velocity magnitude, it will not affect the resulting structure of the wave generated in the acceptor bomb.

The next calculation involved an actual MK-82 symmetric pallet test. A plane of symmetry along the diagonal was used to reduce the computational burden. The initial setup is shown in Figure 27. Note that the horizontal acceptor now appears to be in the diagonal position but, again, this is simply due to the choice taken for the plane of symmetry. Again, because of size constraints, a well-resolved calculation could not be performed. As a result, magnitudes of the pressures calculated were expected to be low.

This is important since it was desired to see what effect, if any, a detonation front generated in the acceptor explosive, due to donor casewall impact, would have on the reliability of pin data. A modified Forest Fire (burn model developed at Los Alamos) type run up was employed to look at the detonation wave inside the acceptor explosive. The event modeled is that of a live diagonal acceptor with an inert horizontal and vertical adjacent acceptor. Again, the purpose of the calculation was to examine the round-to-round interaction environment in order to better instrument the actual test.

The calculational sequence is shown in Figures 27 through 29. By 130 μs, the horizontal acceptor has been impacted by the donor casewall. Because of the poor resolution, the donor casewall appears to be breaking up by 200 μs. It may, in reality, be fragmented by this time; however, the aerial density of the fragmented case is almost no different from the unfragmented case so that, to the acceptor, little difference can be observed. Note also that a fairly thick flat plate has been formed on the diagonal (near the centerline). By 200 μs, impact has occurred. The initial impact area is between $z = 45$ and $z = 55$ cm. Experimentally, the initial impact area has been postulated at approximately 52 cm (from pin data). The calculation confirms the approximate location but, again, due to the poor resolution, little else can be determined. At $z = 52$ cm, the velocity at impact is 1.45 km/second. While this velocity is lower than that calculated at the maximum cross section, ($z = 68.04$ mm, $v = 1.52$ km/second), the slightly thicker wall (2.69 cm at $z = 52$ cm, 2.58 cm at 68.04 cm) evidently raises the pressure enough for detonation to occur.

Since the impact velocities between the two and three calculations agreed to within a percent, a finely resolved two-dimensional calculation should adequately predict the impact pressures. The impact velocity as a function of axial length up the MK-82 is plotted in Figure 30. Impact velocities for the side-by-side and pallet test calculations were almost identical. This result reinforces the statement made in Section II that confinement has little effect upon impact velocity.

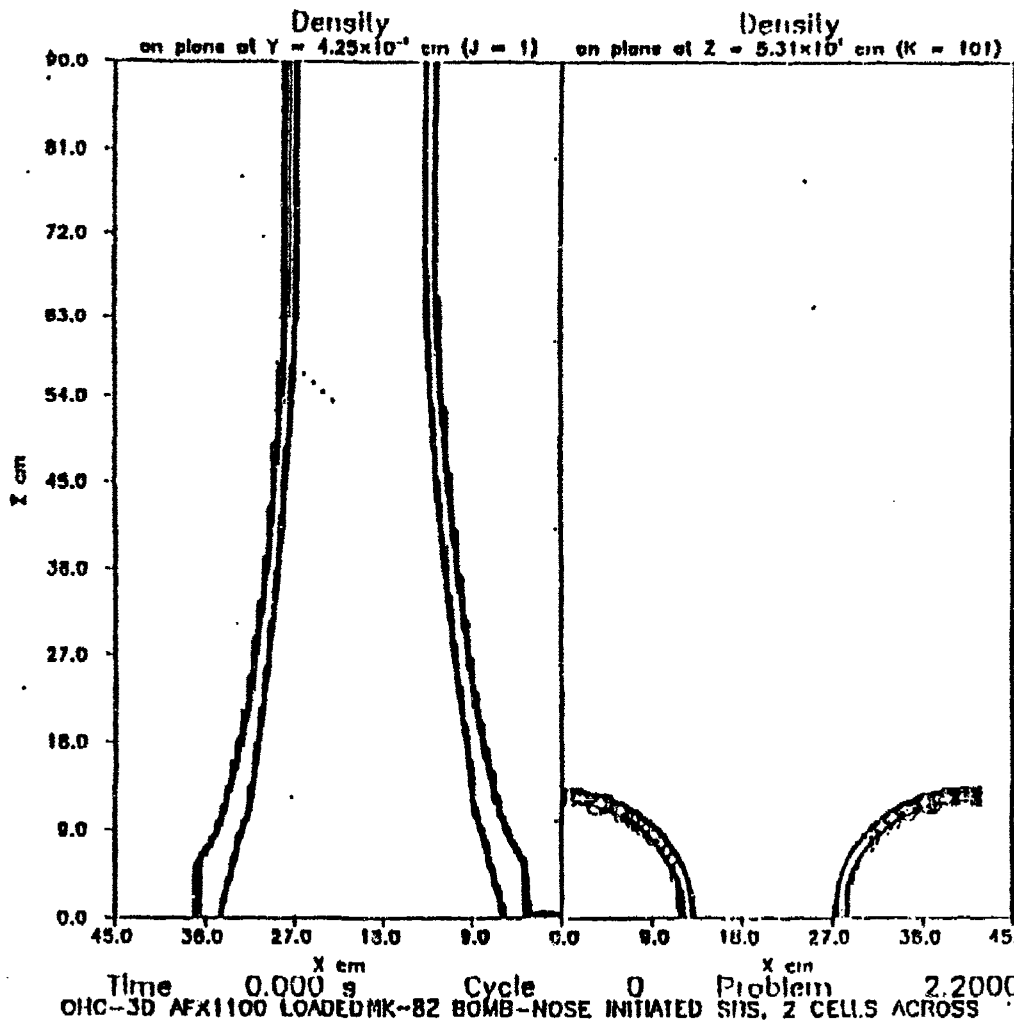


Figure 22. MK-82 Side-by-Side Configuration Initial Setup

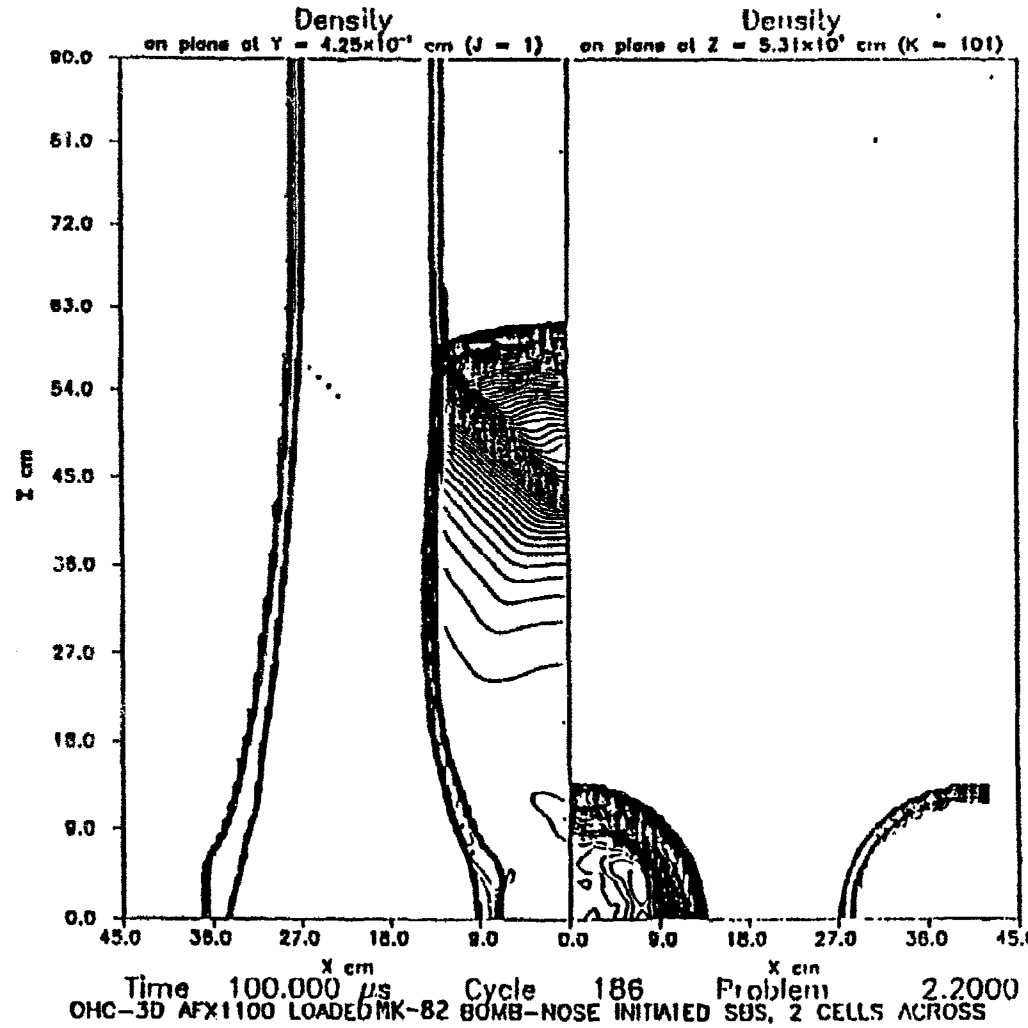


Figure 23. MK-82 Side-by-Side Configuration at 100 μs

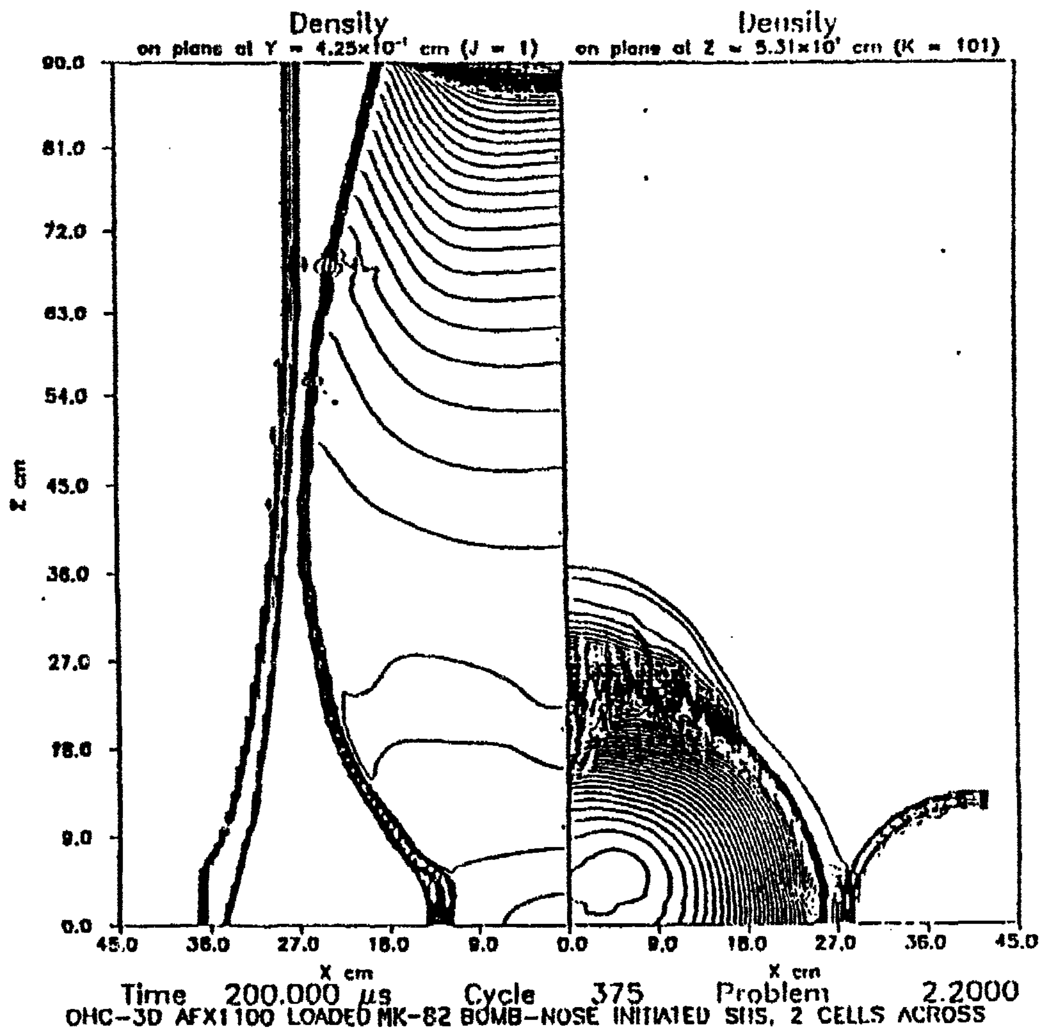


Figure 24. MK-82 Side-by-Side Configuration at 200 μs

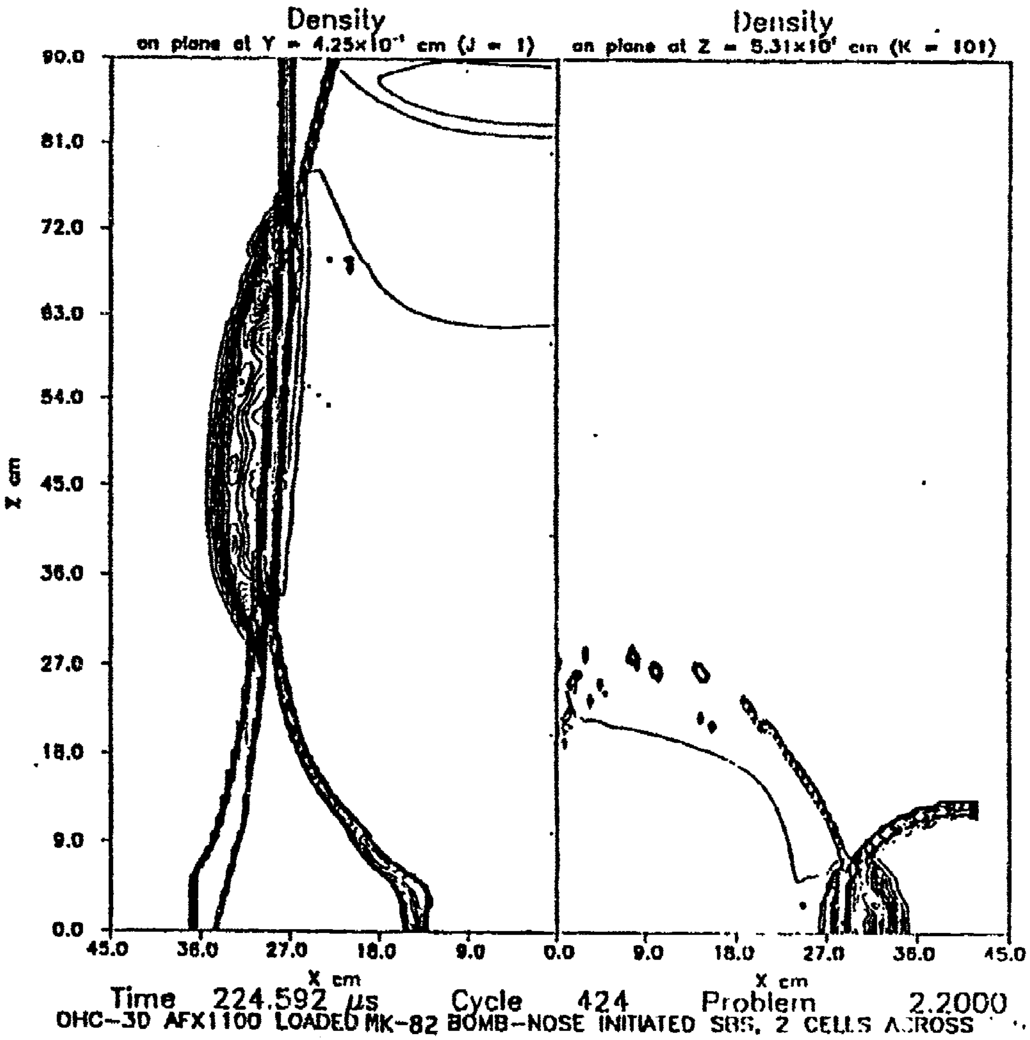


Figure 25. MK-82 Side-by-Side Configuration at 224 μs

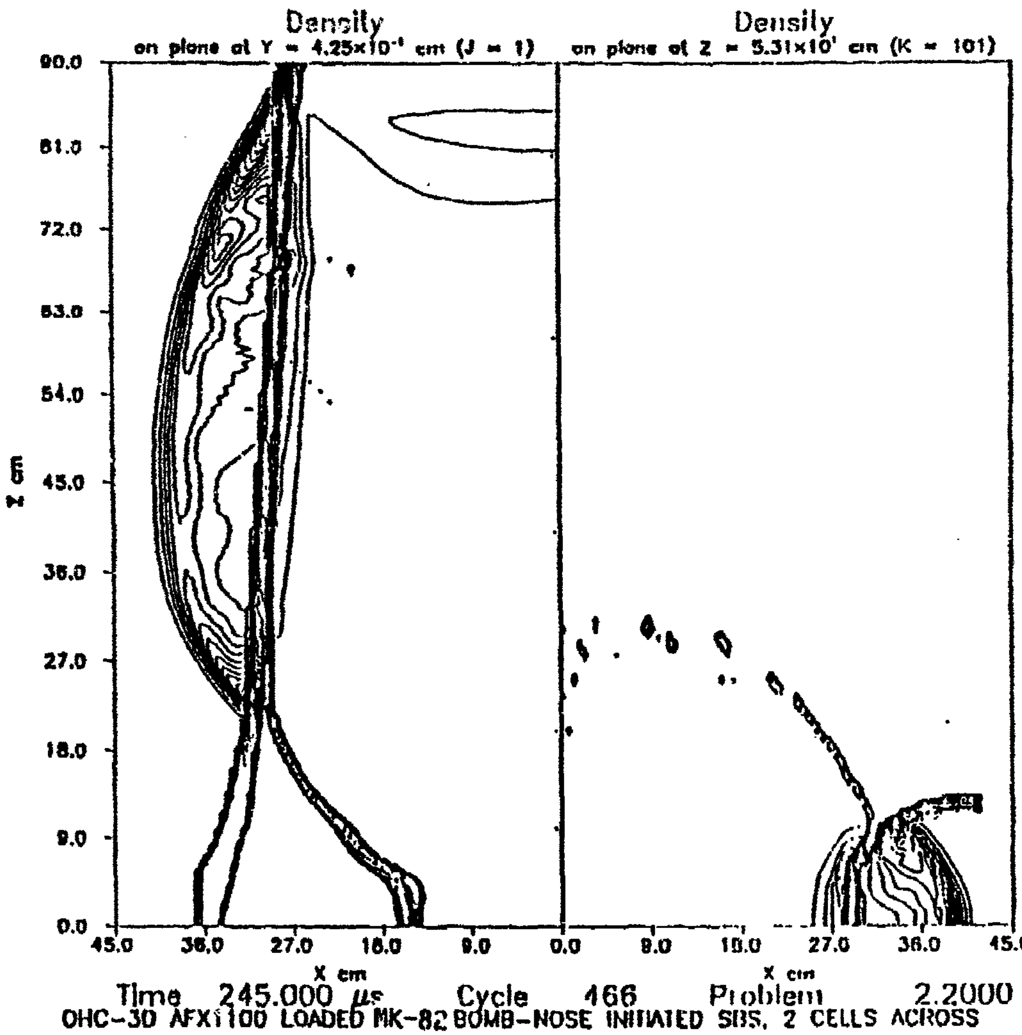


Figure 26. MK-82 Side-by-Side Configuration at 245 μs

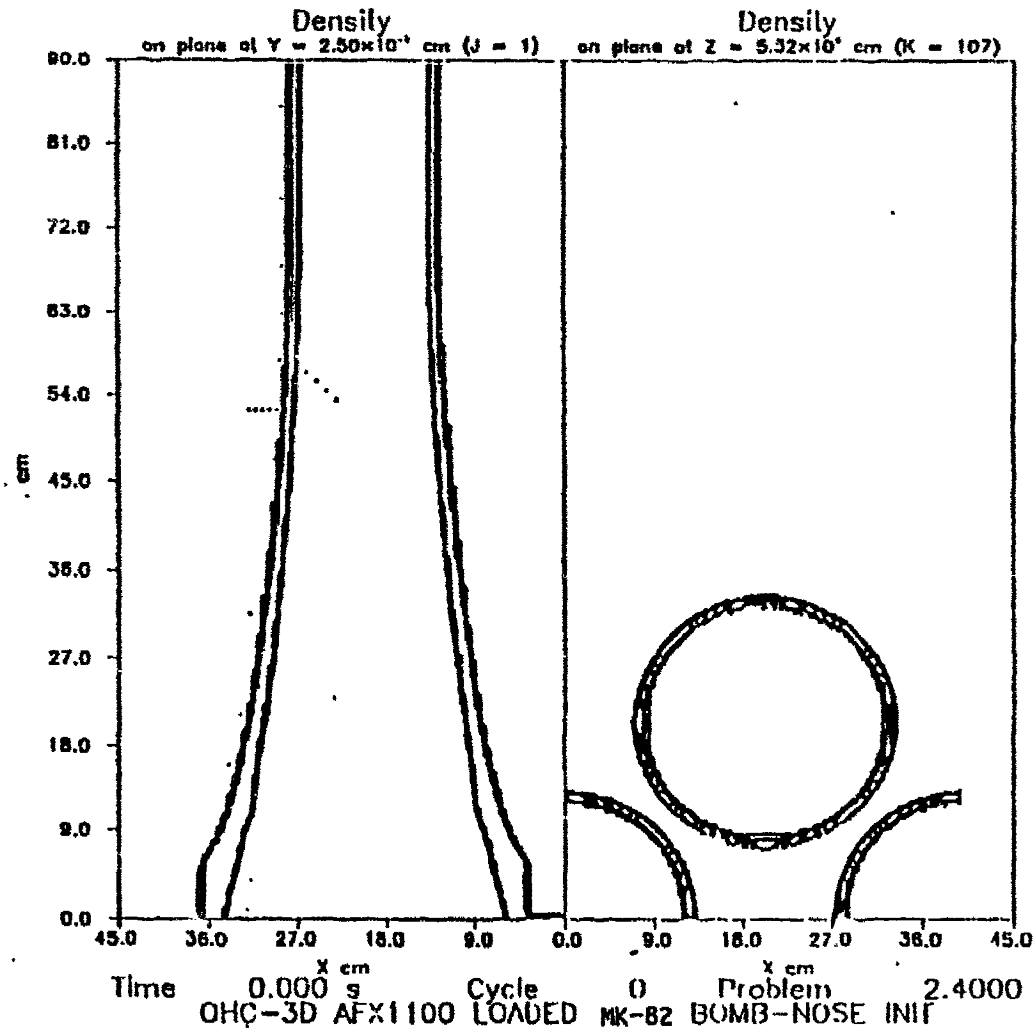


Figure 27. MK-82 Pallet Test Initial Setup

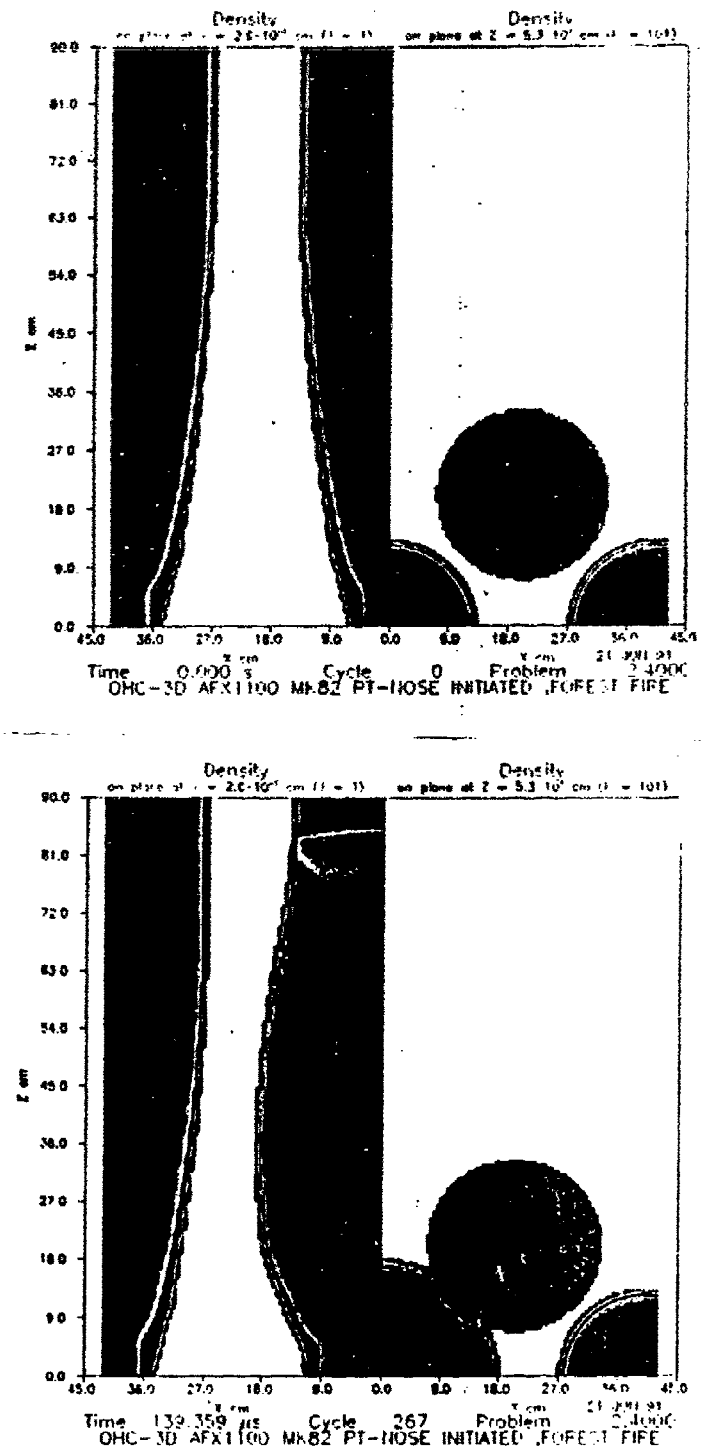


Figure 28. MK-82 Pallet Test (0 - 139µs)

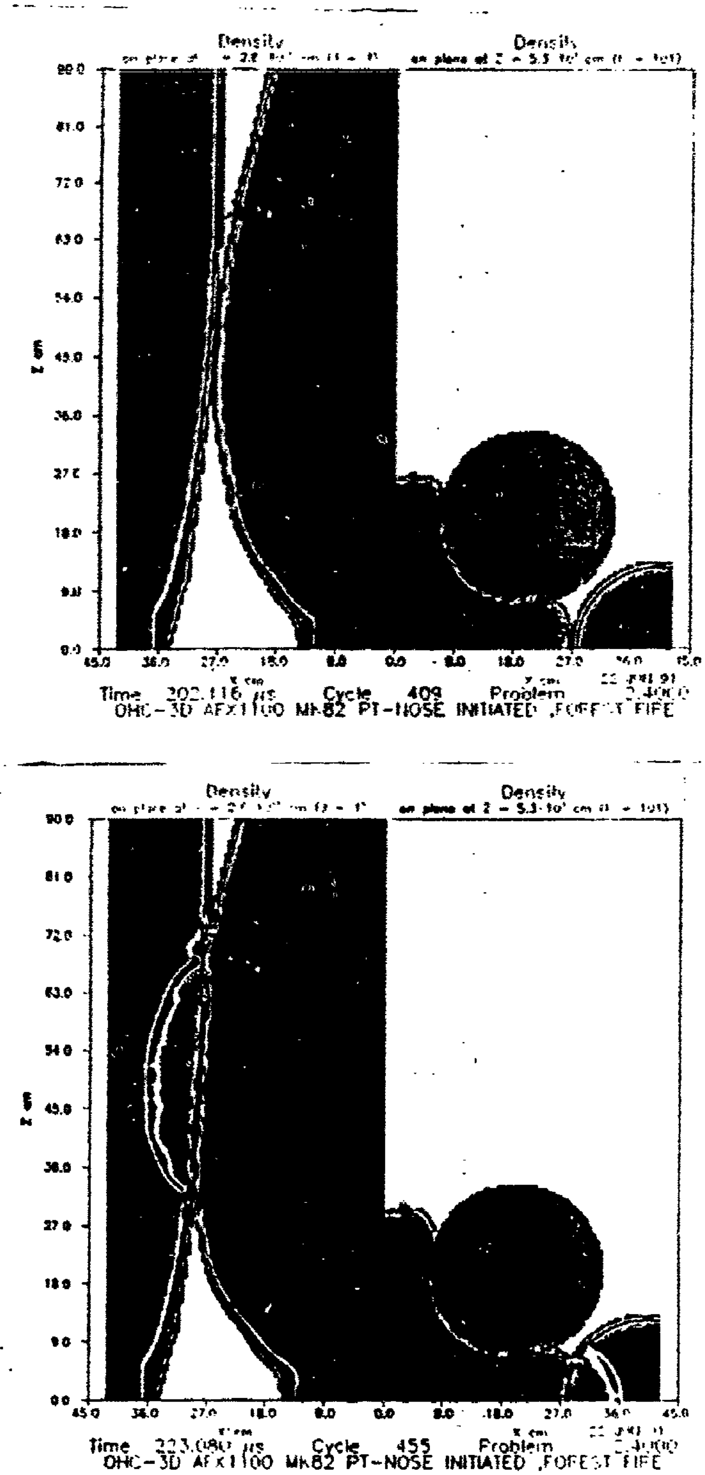


Figure 29. MK-82 Pallet Test (200 - 223 µs)

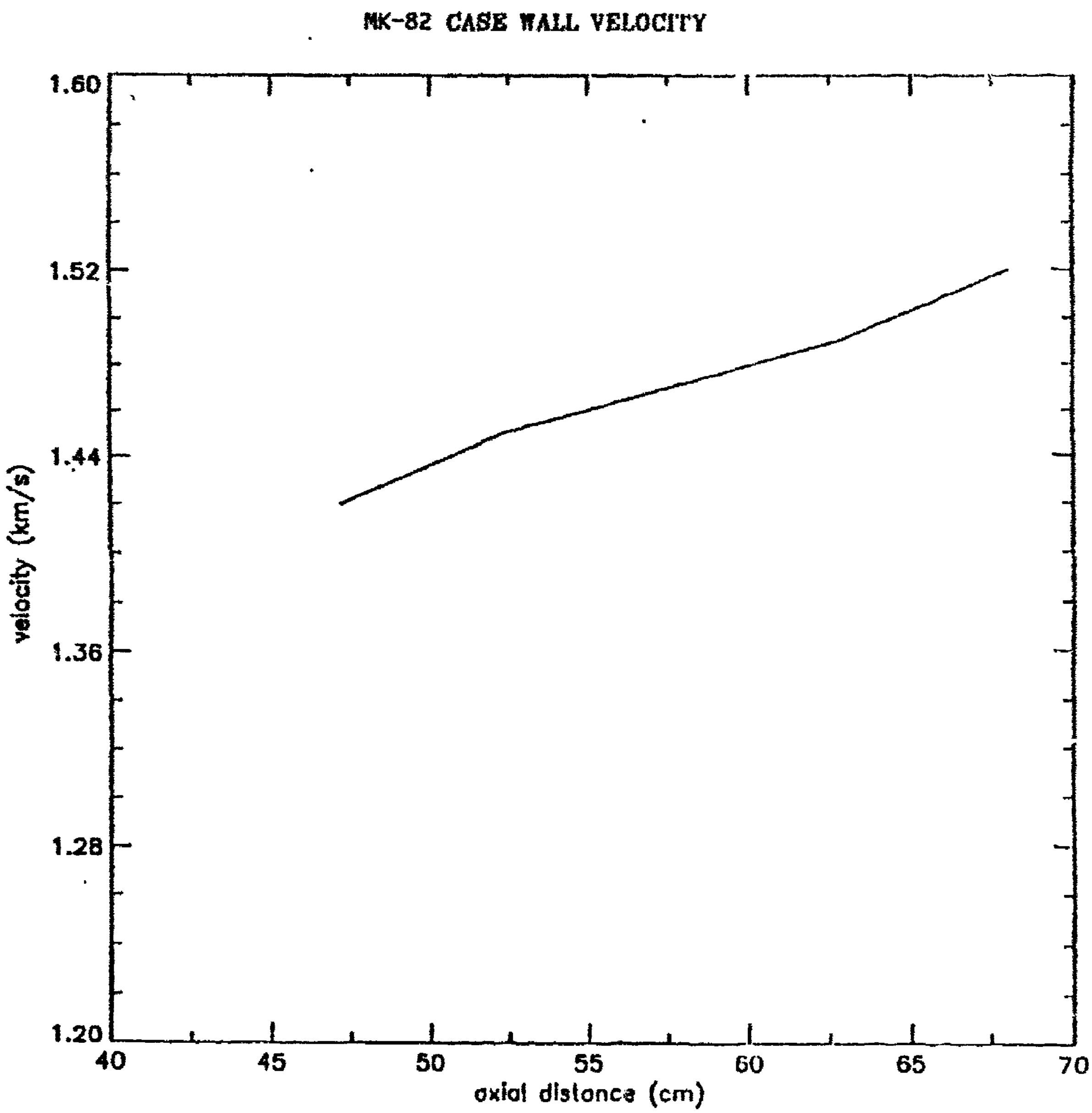


Figure 30. MK-82 Pallet Test Donor Casewall Impact Velocity as a function of Axial Length of Donor Bomb

SECTION VII

SDT MEASUREMENT INSIDE A MK-82

A final experiment was performed based on previous information gathered from MSTAR data and two-and three-dimensional Hull calculations for the diagonal bomb. This experiment was designed to measure the transition to detonation position inside the diagonal acceptor bomb,filled with AFX-1100, during the impact of the donor casewall. Figure 31 is a nose view of the test setup. Three sets of 7 pins were placed in a bisecting fashion to the length of the bomb at 480, 520, and 580 mm as measured from the nose of the bomb. The position of the pins was determined by the earlier information afforded by MSTAR data from inert diagonal bombs. Figure 32 shows a close-up of the 27 piezoelectric pins with pin cables attached.

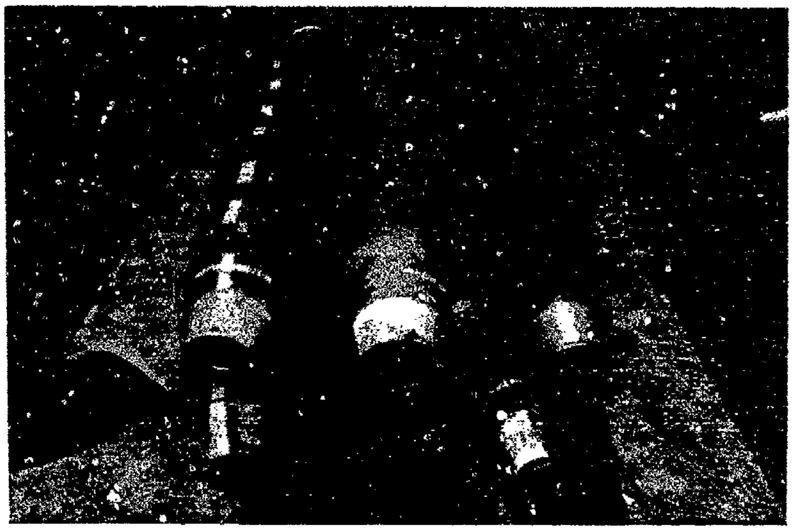


Figure 31. Pallet of 6 MK-82 Bombs, Instrumented Bomb is Donor in the Bottom Middle Position

The piezoelectric pins were 6 inches long and were placed along the centerline of the bomb. X-rays were taken to verify that the pin position did not change during the casting and cooling of the explosive. The pins were 25 mm apart, and the first pins in each set were 41 mm from the inside surface of the bomb casing as shown in Figure 33. Three sets of pins were used to prevent any possible loss of data.

Figure 32. Close-up View of the MK-82 Bomb With the Piezoelectric Pins and Pin Cables

Two of the three sets of pin data yielded information. Both sets of pins measured a detonation velocity of 6.3 km/second from the first to last pin. Since the first pins were 41 mm from the inside surface of the casewall, it appears that the detonation probably occurred somewhere in this area. In reference to the pop-plot data for AFX-1100, for an input pressure of 58 kbars, the run to detonation distance has been measured at 22.5 mm. As shown earlier in this paper the calculated input pressure from the impacting donor casewall is approximately 56 kbars. Therefore, the data suggests that the transition to detonation occurred somewhere in the first 25 mm of run distance for this explosive. The data from this test does indeed verify that a detonation did occur somewhere before the first pin. The equation used to calculate the run to detonation distance is

$$\text{Equation 1: } X^2 = (1128.8)Po^{-2.216}. \tag{1}$$

This equation was developed from the wedge test data. For more information refer to Reference 3.

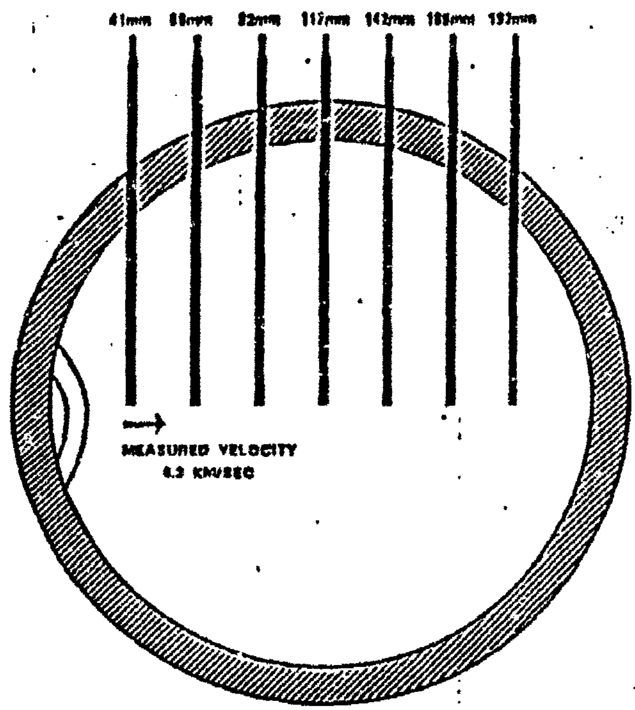


Figure 33. Cross Section of the MK-82 Bomb With the Piezoelectric Pins and the Shock Wave Depicted Moving Into the Explosive

SUMMARY

Full-scale sympathetic detonation tests of MK-82 bombs showed that acceptors in the diagonal position relative to the donor consistently detonated while adjacent bombs did not. An investigation was undertaken to determine what was different in terms of the shocks transmitted to the various acceptors. The investigation characterized the shape and velocity of that element of the donor that initiated detonation in the acceptor. It was discovered through the use of hydrocodes that the confinement was not enhancing the casewall velocity, it was causing the expanding bomb casing to fracture early, and a relatively flat, thick plate was being produced. The velocity of the plate was 1.55 km/second. This combination of velocity and plate thickness produced a high enough pressure (55 kbars) with a pulse duration sufficiently long enough to induce a detonation inside the acceptor explosive. It was found that when the top row of bombs was elevated, the donor bomb was allowed to expand more, the bomb casing thinned,and the diagonal bomb no longer detonated. The velocity was actually higher; however, with the thinned bomb casing, the pulse duration was shorter. The pressure induced in the acceptor explosive was calculated to be 44 kbars. Based on these findings one of the avenues of solutions for suppressing sympathetic detonation in stored munitions may be understanding how to stack munitions to prevent some of these very detrimental effects. Another solution could be a combination of an IHE with a change in the stack geometry. It is all very system specific.

A special recorder was designed and demonstrated in support of this program. The recorder (MSTAR) was used to determine shock wave arrival time and thereby, the shock trajectory induced in the acceptors.

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3. J. C. Dallman, "Characterization of Air Force AFX-1100 II" LA-UR-88-4221, Los Alamos National Laboratories, New Mexico, June 1988.

4. M. E Gunger, Progress on tasks under the Sympathetic Detonation Program, WL/MN-TR-91-85, Wright Laboratory, Armament Directorate, Eglin AFB Florida, December 1992.

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